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SHORT RESEARCH COMMUNICATION

Factor analysis of rock, soil and water geochemical data from Salem magnesite mines and surrounding area, Salem, southern India

M. Satyanarayanan[1] · S. Eswaramoorthi[2] · S. Subramanian[3] · P. Periakali[4]

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Abstract Geochemical analytical data of 15 representative rock samples, 34 soil samples and 55 groundwater samples collected from Salem magnesite mines and surrounding area in Salem, southern India, were subjected to R-mode factor analysis. A maximum of three factors account for 93.8 % variance in rock data, six factors for 84 % variance in soil data, five factors for 71.2 % in groundwater data during summer and six factors for 73.7 % during winter. Total dissolved solids are predominantly contributed by Mg, Na, Cl and SO_4 ions in both seasons and are derived from the country rock and mining waste by dissolution of minerals like magnesite, gypsum, halite. The results also show that groundwater is enriched in considerable amount of minor and trace elements (Fe, Mn, Ni, Cr and Co). Nickel, chromium and cobalt in groundwater and soil are derived from leaching of huge mine dumps deposited by selective magnesite mining activity. The factor analysis on trivalent, hexavalent and total Cr in groundwater indicates that most of the Cr in summer is trivalent and in winter hexavalent. The gradational decrease in topographical elevation from northern mine area to the southern residential area, combined regional hydrogeological factors and distribution of ultramafic rocks in the northern part of the study area indicate that these toxic trace elements in water were derived from mine dumps.

Keywords Groundwater · Geochemical data · Statistical analysis · Salem · Tamil Nadu

Introduction

Environmental data are strongly characterized by inherent variability, and only limited understanding of the environmental distribution of contaminants can be gained from chemical analysis (Agterberg 1974; Davis 2002; Steube et al. 2009; Machiwal and Jha 2015). Hence, statistical techniques are applied to analyse the data and infer the underlying principle/mechanism involved (Einax et al. 1997; Krishna et al. 2009; Li and Zhang 2010; Tao et al. 2014). Naturally occurring major, minor and trace elements in groundwater can have a significant effect on human and animal health through either deficiency or toxicity due to excessive intake (Frengstad et al. 2001). In India, these issues are widely discussed, out of which most researchers work on arsenic, fluoride and chromium, and other heavy metals contamination in groundwater due to its capability to affect human health and vulnerability of groundwater to change (Godgul and Sahu 1995; Dhakate et al. 2008; Kar et al. 2008; Dhal et al. 2011; Kumar 2014). Several international authors have also discussed in detail on the potential health impact due to release and transport of toxic metals in water (Edmunds and Smedley 1996; Reimann and de Caritat 1998; Frengstad et al. 2001; Cooper 2002; Moncur et al. 2005; Michael 2013; Lado et al. 2013).

The study area (Fig. 1) in and around Salem magnesite mine covers 193 km^2 and is the second largest magnesite mine in India. The rock types in the study area are basic

✉ M. Satyanarayanan
icpmsnarayanan@gmail.com

1 CSIR-National Geophysical Research Institute, Hyderabad 500007, India

2 Curtin University, CDT 250, 98009 Miri, Sarawak, Malaysia

3 CGWB, South East Coastal Region, Chennai 600090, India

4 Department of Applied Geology, University of Madras, Chennai 600025, India

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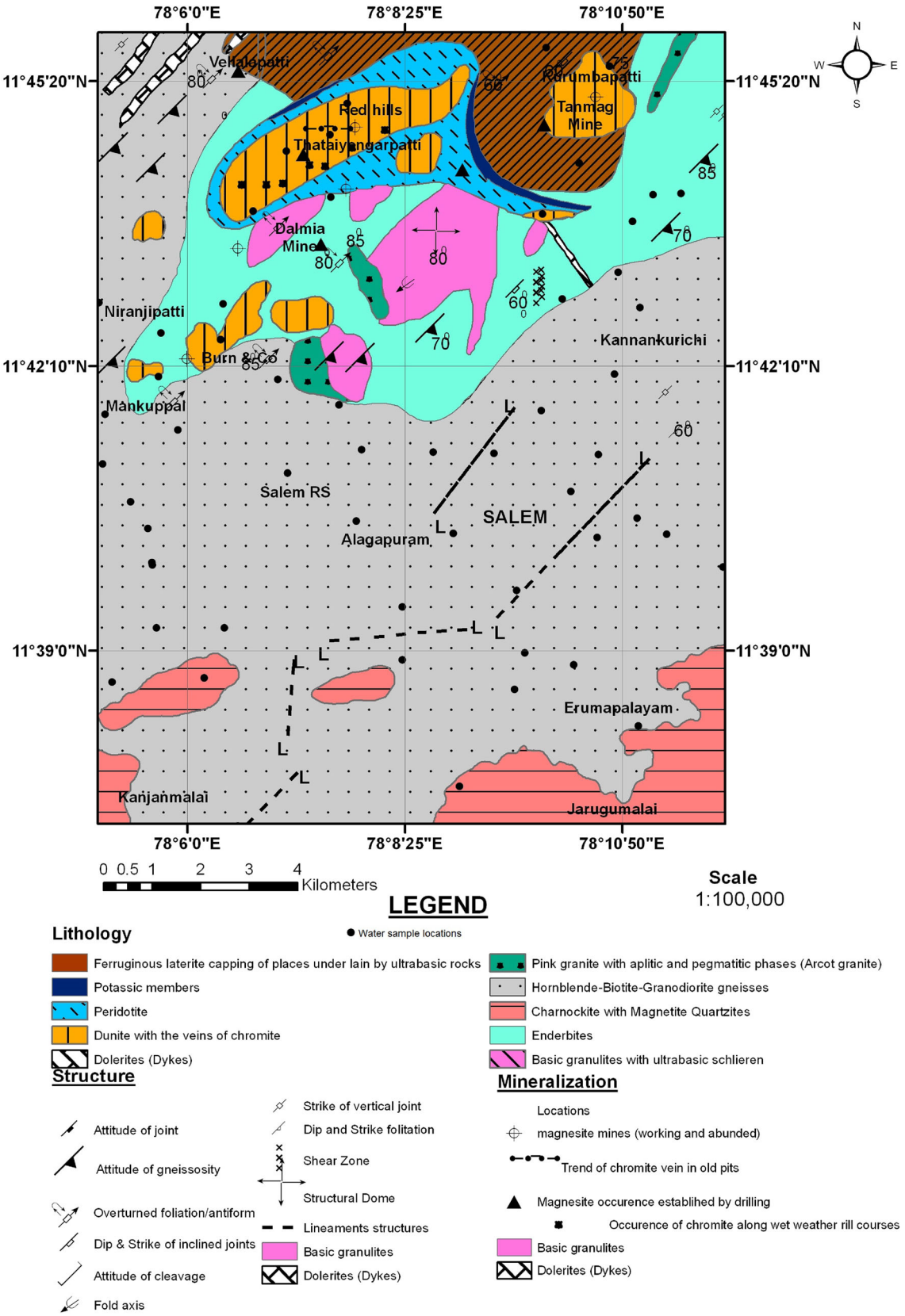

Fig. 1 Geological map of the study area in Salem, southern India (Modified after Periakali 1982)

granulites, hornblende–biotite granodiorite, gneisses and amphibolite, pink granite, pegmatites, dolerites, ultramafic and alkaline rocks. The ultramafic and alkaline rocks are composed of dunites, peridotites, shonkinites and syenites and are important as they are major contributors to the trace element budget of soil and water. They occur as intrusives amidst the highly metamorphosed rocks (amphibolites and granulites) that have been subjected to successive periods of deformation. The weathering of ultramafic rocks has resulted in not only the enrichment of trace elements particularly Ni, Cr and Co in soil, and subsequently in groundwater, but also deterioration of water quality (Periakali et al. 1999). The analytical data obtained from rock, soil and water samples were used to derive inter-element associations and to understand factors contributing to groundwater quality. In the present study, factor analysis has been carried out to show the interrelationship existing between a number of variables with the help of few factors.

Factor analysis

The R-mode is chosen as it has several positive features in interpreting geochemical data (Lawrence and Upchurch 1982). The raw data were standardized to have a mean of zero and standard deviation of one. Correlation coefficient r is given by the equation.

$$r = (dx.dy)/\left(n\sum x.\sum y\right) \quad (1)$$

where dx, dy are the mean derivatives of values in x and y series, n is the number of items and $\sum x$, $\sum y$ are the standard deviations of x and y (Davis 2002). Correlation coefficients of the variables are computed from the standardized variables. The correlation coefficient matrix quantifies the linear relationship existing between pairs of variables present therein. The percentages of eigenvalues are computed since the eigenvalues quantify the contribution of a factor to the total variation. The contribution of a factor is said to be significant when the corresponding eigenvalue is greater than unity. The factor 1 will be related to the largest eigenvalue and will explain the greatest amount of variance in the data set. The factor 2 explains the greatest of the remaining variance and so forth. Regionally distributed, lithologically controlled variables are generally extracted first and then the more local pathway/origin controlled variables are identified (Lawrence and Upchurch 1982). A step has been taken to rotate the factors (varimax rotated) in such a way that all their components are closer to +1, 0 or −1, representing the importance of each variable (Briz-Kishore and Murali 1992; Davis 2002). Thus, where factor loadings are high, it can be assumed that the variable contributes to that factor (Lawrence and Upchurch 1982). If the factor loadings have a negative sign, it indicates a negative correlation with the factor.

Methodology

Thirty-four soil samples were collected and analysed for major oxides (SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO, MgO, CaO, Na_2O and K_2O), and minor and trace elements (Fe, Mn, Ni, Cr and Co) following standard procedures (Jackson 1967). The analytical error in terms of the %RSD for major oxides varied from 2 to 3 %, while for the minor and trace elements, it is between 2 and 6 %. Major ion chemistry, SiO_2, pH, EC, total dissolved solids (TDS), Ca, Mg, Na, K, Cl, SO_4, CO_3, HCO_3 and NO_3, and minor and trace elements (Fe, Mn, Ni, Cr and Co) were determined from 55 groundwater samples taken for six different periods [summer (May) and winter (November) seasons from 1997 to 1999] following standard procedures (APHA 1995). The analytical data thus acquired were within the permissible analytical errors (better than 3 % RSD). Trivalent and hexavalent chromium were determined using chemical separation and analysis by Atomic Absorption Spectrometry (Varian® SpectrAA 200) for the samples collected during summer and winter seasons of 1997 and 1998. The data for 1999 were not acquired due to constraints in analytical work. The standard error for chromium speciation data varied from 2 to 3 %. All chemical analysis was carried out at the University of Madras (Guindy campus), Chennai, India. The soil and water analytical data are presented in Satyanarayanan and Periakali (2002, 2003 2004). The analytical data of fifteen ultramafic rock samples of Periakali (1982) for the study area were utilized to compare and contrast the inferences obtained from the analysis of soil and water. Only those parameters that were determined for soil and water were statistically analysed to understand the nature of association of various components. The geochemical data were further subjected to R-mode factor analysis using SPSS (Statistical Package for Social Sciences 1995) software (version 7.5) and the statistically significant factors extracted.

Results and discussion

Rock

The factor analysis data (Table 1) were used to infer the factors responsible for the distribution of trace elements (Ni, Cr and Co) in ultramafic rocks. The data show that three factors account for 93.8 % of the variance in the data. Factor 1, which describes 71.5 % of the variance, has

Table 1 Factor analytical results of rock samples from the study area

Variable	Communality	Factor	Eigen value	% of Var	Cum %	Factor 1	Factor 2	Factor 3
% Al	1.00	1	8.59	71.50	71.50	**−0.95**	−0.29	−0.09
% Ca	0.90	2	1.63	13.60	85.10	0.35	**0.71**	**0.53**
Co	0.98	3	1.04	8.70	93.80	**0.96**	−0.14	0.19
Cr	0.99	4	0.63	5.20	99.00	**0.89**	0.43	−0.07
% Fe	0.84	5	0.11	0.90	99.90	0.29	0.43	**0.75**
% K	1.00	6	0.01	0.10	100.00	**−0.94**	−0.34	−0.06
% Mg	0.99	7				**0.97**	0.22	−0.03
% Mn	0.88	8				0.27	**0.90**	−0.06
% Na	0.99	9				**−0.94**	−0.33	−0.06
Ni	0.99	10				**0.94**	0.32	0.08
% Si	0.99	11				**−0.85**	−0.43	−0.28
% Ti	0.70	12				−0.10	−0.13	**0.82**

Significant factor loadings with more than 0.50 are given in bold

positive loading on nickel, chromium, cobalt and magnesium, and negative loading on silica, aluminium, sodium and potassium. This indicates that the trace metals nickel, chromium and cobalt are enriched and associated with each other in the ultramafic rocks, as observed by many workers in the study area (Windley and Selvan 1975; Viswanathan and Nagendra Kumar 1982; Periakali 1982; Kutty et al. 1986; Reddy et al. 1995; Subramanian and Selvan 2001). Silica, aluminium, sodium and potassium show a negative trend in ultramafic rocks. Factor 2, which describes 13.6 % of the variance, has positive loading on calcium and manganese. Factor 3 describes 8.7 % of the variance, with positive loading on total iron, titanium and calcium and it explains their contribution from the accessory mineral titanomagnetite of ultrabasic rocks of the study area (Kalaiselvan 1994).

Soil

Factor analytical results (Table 2) were used to determine the factors responsible for the distribution of trace elements in soil. The results show that six factors account for 84 % of the variance in the data. Factor 1, which describes 25.6 % of the variance, has high positive loading on CaO and MgO, and negative loading on Al_2O_3 and SiO_2. This shows that the type of soil in the study area is calcimagnesian rather than aluminosilicate. Factor 2, which describes 21.9 % of the variance, has positive loading on nickel, chromium and cobalt indicating their association with each other and derivation from a common source. Factor 3, which describes 12.5 % of the variance, has positive loading on pH, TiO_2 and K_2O and negative loading on $CaCO_3$, implying that at high pH, the oxides of titanium and potassium are mobile when compared to calcium carbonate in soils. Factor 4, which describes 11.3 % of the variance, has positive loading on silt and negative loading on sand. This factor explains that the sand percentage in soil decreases with increase in silt content. Factor 5, which describes 6.6 % of the variance, has positive loading on Fe_2O_3 and MnO, which shows that manganese is related to iron in its chemical properties and is a member of the iron family (Raymahashay 1996) or the ferrides (Krauskopf 1979). Factor 6, which describes 5.9 % of the variance, has positive loading on clay percentage and organic carbon. The association of clay with organic carbon clearly confirms the affinity of humic substances to clay-sized particles.

Groundwater quality in summer

The factor analytical results show that five factors account for 71.2 % variance in the data (Table 3). Factor 1 is loaded with Ec, TDS, Mg, Cl, Na and SO_4, and it accounts for 30.4 % of the variance. This shows that the TDS are influenced by the major ions of Mg, Na, Cl and SO_4. This factor can be explained for large residence time of groundwater/low hydraulic conductivity, greater rock–water interaction and greater solubility of minerals (Scanlon, 1989; Henry and Shwartz 1990). Salem district is underlain entirely by Archaean rocks comprising granite gneiss, charnockite, granites and other associated consolidated crystalline rocks devoid of primary porosity but rendered porous and permeable with the development of secondary fracturing, inducing relatively longer residence time of groundwater. The pumping rate in bore wells varies from 20 to 500 lpm and depends on the depth of the bore well (Subburaj, 2008). High loading on SO_4 indicates pollution from application of fertilizers to agricultural lands or industrial pollution (Berner and Berner 1987; Scanlon 1989; Cain et al. 1989). Simple irrigation system in which

Table 2 Factor analytical results of soils collected from the study area

Variable	Communality	Factor	Eigen value	% of Var	Cum %	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Al_2O_3	0.75	1	4.87	25.60	25.60	**−0.73**	−0.25	0.34	0.09	−0.11	−0.14
$CaCO_3$	0.79	2	4.17	21.90	47.60	0.15	−0.03	**−0.84**	0.17	0.15	0.09
CaO	0.97	3	2.38	12.50	60.10	**0.95**	−0.08	−0.15	−0.07	−0.18	0.08
CEC	0.48	4	2.15	11.30	71.50	0.36	−0.05	0.05	0.30	−0.13	0.48
Clay (%)	0.73	5	1.26	6.60	78.10	−0.08	−0.23	0.05	−0.32	0.03	**0.75**
Co	0.96	6	1.12	5.90	84.00	−0.05	**0.96**	−0.05	0.05	0.20	−0.01
Cr	0.95	7	0.78	4.10	88.10	−0.07	**0.95**	−0.09	0.05	0.15	−0.07
Fe_2O_3	0.95	8	0.67	3.50	91.60	−0.18	0.15	−0.04	−0.08	**0.94**	−0.06
K_2O	0.71	9	0.52	2.70	94.30	−0.01	−0.23	**0.78**	0.22	0.06	−0.04
MgO	0.97	10	0.38	2.00	96.30	**0.95**	−0.08	−0.15	−0.07	−0.18	0.08
MnO	0.94	11	0.35	1.80	98.10	−0.08	0.45	−0.02	−0.11	**0.85**	−0.08
Na_2O	0.88	12	0.15	0.80	98.90	−0.15	−0.49	0.76	−0.09	−0.17	−0.08
Ni	0.93	13	0.11	0.60	99.50	−0.12	**0.84**	−0.40	0.10	0.16	0.05
OC	0.59	14	0.06	0.30	99.80	0.19	0.18	−0.21	0.01	−0.07	**0.68**
pH	0.74	15				0.43	0.38	**0.62**	−0.06	−0.06	−0.17
Sand (%)	0.94	16				0.13	−0.06	0.00	**−0.96**	0.07	0.01
Silt	0.97	17				−0.11	0.09	−0.01	**0.96**	−0.07	−0.11
SiO_2	0.96	18				**−0.88**	0.29	−0.29	0.09	0.05	−0.07
TiO_2	0.74	19				−0.22	−0.28	**0.69**	0.05	0.33	0.15

Significant factor loadings with more than 0.50 are given in bold

Table 3 Factor analytical results of groundwater samples collected during summer in the study area

Parameter	Communality	Factor	Eigen value	% of Var	Cum %	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Ca	0.56	1	5.77	30.40	30.40	0.24	0.07	0.32	**−0.51**	0.36
Cl	0.83	2	2.67	14.10	44.40	**0.82**	0.08	−0.29	0.12	0.24
Co	0.49	3	2.11	11.10	55.50	0.38	−0.24	**−0.52**	−0.15	0.02
CO_3	0.66	4	1.69	8.90	64.40	0.00	−0.15	**0.79**	−0.07	0.08
Cr	0.58	5	1.47	7.80	72.20	−0.04	−0.11	0.26	−0.16	**−0.69**
Depth	0.63	6	0.91	4.80	77.00	0.07	−0.03	0.01	0.03	**0.79**
Ec	0.99	7	0.83	4.40	81.30	**0.94**	0.28	0.01	0.05	0.14
Fe	0.67	8	0.72	3.80	85.10	0.05	0.02	−0.09	**0.69**	0.42
HCO_3	0.69	9	0.61	3.20	88.30	0.19	**0.60**	0.39	−0.24	0.29
K	0.92	10	0.57	3.00	91.30	0.08	**0.95**	−0.04	0.04	−0.03
Mg	0.73	11	0.51	2.70	94.00	**0.75**	−0.07	0.33	0.22	−0.05
Mn	0.75	12	0.37	1.90	95.90	0.27	0.06	0.00	**0.82**	0.09
Na	0.82	13	0.34	1.80	97.70	**0.78**	0.34	−0.28	0.05	0.14
Ni	0.49	14	0.23	1.20	98.90	0.37	0.00	0.27	**0.53**	−0.03
NO_3	0.93	15	0.19	1.00	99.90	0.16	**0.95**	−0.04	0.08	0.01
pH	0.73	16				−0.39	0.05	**0.67**	−0.30	−0.17
Si	0.44	17				−0.04	−0.06	**−0.60**	−0.10	0.25
SO_4	0.82	18				**0.84**	−0.17	−0.16	0.16	−0.20
TDS	0.99	19				**0.94**	0.28	0.00	0.05	0.13

Significant factor loadings with more than 0.50 are given in bold

water from dug wells is used for growing crops in the study area. Fertilizers such as urea, diammonium phosphate (DAP), potash are used during farming in these regions. A number of industrial units including textile units, sugar mills and sago factories exist in Salem district, the effluents from which have caused local pollution of surface and

ground water resources. Excessive use of fertilizers and pesticides in agriculture has also reportedly resulted in localized enrichment of sulphates and nitrates in the phreatic zone (Subburaj 2008). Factor 2 is loaded with K, HCO_3 and NO_3 and accounts for 14.1 % of the variance. This factor indicates the supply of K and NO_3 to the soil through the application of fertilizers and infiltration into the groundwater (Ballukraya and Ravi 1999). Factor 3, which describes 11.1 % of the common variance, has positive loading for pH and CO_3 which indicates that the alkalinity of groundwater is associated with post-rainfall periods, when an increase in pH of the groundwater is noticed. When the carbonate hydrolyses, it produces the bicarbonate ion and hydroxide ion. The hydroxide ion makes the solution basic. [$CO_3^{2-} + H_2O <==> HCO_3^- + OH^-$]. Increase in pH leads to conversion of HCO_3 to CO_2 (Berner and Berner 1987). A detailed account of the water type using Piper diagram is given elsewhere (Satyanarayanan and Periakali 2002). Further, it was observed that the concentrations of Co and silica, determined by geogenic influences, have negative loading and decrease with increase in alkalinity. Factor 4, which describes 8.9 % of the common variance, has positive loading for Fe, Mn and Ni, and negative loading for calcium. This shows that the influence of Fe- and Mn-bearing minerals rather than Ca is predominant in increasing the concentration of Ni during summer. Factor 5 has positive loading for depth and negative loading for Cr, accounting for 7.8 % of the variance. This clearly explains that in the upper layer, the influence of Cr predominates than in the deeper layers. These investigations, when correlated with field observations, reveal that the increased concentration of Cr in groundwater is due to magnesite mineralization in ultrabasic rocks.

Groundwater quality in winter

During winter, the factor analytical results show that six factors account for 73.7 % of the variance of the data (Table 4). Factor 1 is loaded with Ec, TDS, Mg, Na, Cl and SO_4, and it accounts for 30.9 % of the variance. Similar observations during summer reveal that the TDS is influenced mainly by the major ions of Mg, Na, Cl and SO_4, and the groundwater chemistry is controlled by these four ions in the study area. Factor 2, which describes 11.3 % of the variance, has high positive loading for K and NO_3, influenced by rainfall on the application of fertilizers to the soil and their infiltration into the groundwater system. K and NO_3 are major pollutants (Berner and Berner 1987; Melloul and Collin 1992). High positive loading of K can be attributed to the application of fertilizers in the agricultural areas as is also evident from inferences drawn on groundwater quality in summer. Similarly, high positive loading of nitrate is from domestic sewage effluents. The oxic environment prevailing in sand aquifers promotes nitrate formation from sewage sources (Scanlon 1990; Peddorson et al. 1991). Factor 3, which describes 9.8 % of the variance, is positively loaded with HCO_3 and negative with silica. High loading on HCO_3 can be attributed to the CO_2 present in the soil. Oxidation of organic matter by microbes generates CO_2, which then combines with water to form carbonic acid (Raymahashay 1996) and dissociates to H and HCO_3 ions.

$$\underset{\text{(Organicmatter)}}{CH_2O} + O_2 \longrightarrow CO_2 + H_2O \quad (2)$$

$$CO_2 + H_2O \longrightarrow H_2CO_3 \quad (3)$$

$$\underset{\text{(Carbonicacid)}}{H_2CO_3} \longrightarrow H + HCO_3 \quad (4)$$

Factor 4, which describes 8.6 % of the variance, has positive loading on depth of the well and Fe, and negative loading on Cr. The association of depth with Cr was also observed during summer season. This indicates, undoubtedly, that the persistence of Cr in groundwater is shallow in nature and influenced by mining activity during the recent past. The association of Fe with these components during winter explains that the rainfall and rock–water mechanism act as a predominant factor in influencing the concentration of Cr in groundwater. Factor 5, which describes 7.3 % of the variance, has positive loading for Mn and CO_3, and negative loading for Ni. This indicates that Ni concentration is low in Mn- and CO_3-enriched environment. Factor 6, which describes 5.9 % of the variance, is positively loaded with Co and negatively loaded with Ca, confirming that Co concentration is low in Ca-rich groundwater of the study area.

Trivalent and hexavalent chromium in groundwater

Factor analysis was applied to a matrix of 110 samples (55 in each season) and 21 water components collected and analysed during 1997 and 1998 to find out the main influences on seasonal changes in the trivalent and hexavalent chromium loading in groundwater. The results of the factor analysis from data obtained during summer and winter are given in Tables 5 and 6, respectively. The factor analytical results during summer show that six factors account for 75.8 % of the variance in the data (Table 5). Trivalent and total Cr are negatively loaded on factor 3, which describes 11.6 % of the variance. Depth of the well is loaded positively, as observed earlier for total chromium. This indicates that during summer, total Cr is in the form of Cr(III), and with depth, the concentrations of both decrease. The hexavalent form of Cr is located positively on factor 5, which describes 7.5 % of the variance. Ni is negatively loaded on this factor, which shows that an

Table 4 Factor analytical results of groundwater samples collected during winter in the study area

Parameter	Communality	Factor	Eigen value	% of Var	Cum %	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Ca	0.75	1	5.87	30.90	30.90	0.19	0.05	−0.06	0.06	0.15	**0.83**
Cl	0.88	2	2.14	11.30	42.10	**0.85**	0.18	−0.02	0.06	0.11	0.34
Co	0.74	3	1.85	9.80	51.90	**0.58**	0.07	−0.24	0.17	0.00	**−0.55**
CO_3	0.71	4	1.63	8.60	60.50	0.05	−0.01	0.48	−0.04	**−0.69**	−0.01
Cr	0.64	5	1.40	7.30	67.80	−0.03	−0.07	−0.02	**−0.75**	0.21	−0.12
Depth	0.46	6	1.12	5.90	73.70	0.07	−0.10	0.14	**0.64**	0.05	0.08
Ec	0.98	7	0.87	4.60	78.30	**0.93**	0.23	0.13	0.06	0.11	0.16
Fe	0.53	8	0.80	4.20	82.50	−0.06	0.07	−0.01	**0.66**	0.22	−0.18
HCO_3	0.69	9	0.73	3.80	86.30	0.16	0.12	**0.80**	0.08	0.05	−0.03
K	0.98	10	0.57	3.00	89.30	0.20	**0.96**	0.10	0.01	0.08	0.00
Mg	0.79	11	0.53	2.80	92.20	**0.73**	0.01	0.10	−0.06	−0.20	0.44
Mn	0.51	12	0.38	2.00	94.10	0.19	0.09	0.19	0.04	**0.65**	−0.02
Na	0.86	13	0.34	1.80	95.90	**0.81**	0.26	0.13	0.11	0.24	−0.22
Ni	0.68	14	0.28	1.50	97.40	0.28	−0.06	0.08	0.04	**0.65**	0.41
NO_3	0.98	15	0.25	1.30	98.80	0.28	**0.94**	0.10	0.03	−0.01	0.03
pH	0.60	16	0.22	1.20	99.90	−0.41	−0.14	0.25	−0.46	−0.28	0.24
Si	0.69	17				0.09	−0.06	**−0.82**	−0.05	−0.01	−0.06
SO_4	0.75	18				**0.81**	0.07	−0.19	0.01	0.16	−0.16
TDS	0.79	19				**0.86**	0.11	0.13	−0.01	0.13	0.11

Significant factor loadings with more than 0.50 are given in bold

Table 5 Factor analytical results of groundwater samples collected during summer 1997 and 1998 in the study area

Parameter	Communality	Factor	Eigen Value	% of Var	Cum %	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Ca	0.53	1	5.71	27.20	27.20	0.25	0.02	0.21	0.35	0.01	**−0.55**
Cl	0.82	2	2.91	13.90	41.00	**0.83**	0.06	0.26	−0.19	0.08	0.13
Co	0.53	3	2.44	11.60	52.70	0.41	−0.27	−0.02	−0.28	0.46	0.00
CO_3	0.70	4	2.18	10.40	63.00	−0.05	−0.12	0.00	**0.82**	−0.07	−0.05
Cr	0.87	5	1.58	7.50	70.60	−0.05	−0.08	**−0.90**	0.20	0.04	−0.09
Cr(III)	0.86	6	1.08	5.20	75.80	−0.02	−0.13	**−0.89**	0.21	0.05	−0.11
Cr(IV)	0.78	7	0.98	4.70	80.40	0.04	0.10	0.01	−0.17	**0.86**	0.06
Depth	0.46	8	0.80	3.80	84.20	0.11	−0.04	**0.65**	0.12	0.06	0.01
Ec	0.99	9	0.70	3.30	87.50	**0.95**	0.28	0.11	0.08	−0.05	−0.02
Fe	0.76	10	0.62	3.00	90.50	0.12	0.00	0.32	0.11	0.10	**0.79**
HCO_3	0.66	11	0.54	2.60	93.10	0.19	**0.58**	0.15	0.42	−0.03	−0.29
K	0.90	12	0.42	2.00	95.10	0.08	**0.94**	0.01	−0.06	0.00	0.04
Mg	0.71	13	0.36	1.70	96.80	**0.71**	−0.07	−0.04	0.32	−0.28	0.14
Mn	0.78	14	0.26	1.20	98.00	0.28	0.05	0.09	0.06	−0.32	**0.77**
Na	0.80	15	0.22	1.00	99.10	**0.77**	0.36	0.13	−0.22	0.13	0.01
Ni	0.79	16	0.17	0.80	99.80	0.32	0.03	0.00	0.04	**−0.80**	0.22
NO_3	0.93	17	0.02	0.10	99.90	0.16	**0.94**	0.05	−0.05	0.02	0.08
pH	0.73	18				−0.45	0.08	−0.22	**0.59**	−0.15	−0.31
Si	0.50	19				0.01	−0.09	0.20	**−0.63**	0.17	−0.16
SO_4	0.80	20				**0.85**	−0.16	−0.15	−0.15	−0.13	0.05
TDS	0.99	21				**0.95**	0.27	0.11	0.07	−0.04	−0.01

Significant factor loadings with more than 0.50 are given in bold

Table 6 Factor analytical results of Groundwater samples collected during winter 1997 and 1998 in the study area

Parameter	Communality	Factor	Eigen value	% of Var	Cum %	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Ca	0.66	1	6.17	29.40	29.4	0.25	−0.03	0.00	0.11	0.24	**−0.73**
Cl	0.88	2	2.99	14.20	43.6	**0.90**	−0.10	−0.05	0.20	0.10	−0.02
Co	0.79	3	2.30	11.00	54.6	**0.54**	−0.26	−0.36	−0.04	−0.32	0.44
CO_3	0.80	4	1.71	8.20	62.7	0.05	0.03	**0.61**	−0.10	**−0.64**	0.02
Cr	0.81	5	1.42	6.80	69.5	−0.06	**0.86**	−0.06	−0.05	0.12	0.22
Cr(III)	0.79	6	1.15	5.50	75	−0.09	**0.69**	0.14	−0.05	**0.53**	−0.11
Cr(IV)	0.82	7	0.96	4.60	79.5	0.18	**0.88**	−0.01	−0.09	0.03	0.02
Depth	0.30	8	0.81	3.90	83.4	0.11	−0.47	0.16	−0.11	0.17	0.02
Ec	0.98	9	0.69	3.30	86.7	**0.95**	−0.08	0.10	0.21	0.11	−0.04
Fe	0.41	10	0.65	3.10	89.7	−0.01	**−0.52**	−0.03	0.11	0.11	0.34
HCO_3	0.74	11	0.38	1.80	91.6	0.09	−0.09	**0.83**	0.11	0.15	−0.06
K	0.98	12	0.36	1.70	93.3	0.22	−0.05	0.09	**0.96**	0.07	−0.01
Mg	0.77	13	0.34	1.60	94.9	**0.84**	0.10	0.08	0.06	−0.16	−0.14
Mn	0.56	14	0.28	1.30	96.2	0.28	−0.05	0.08	0.19	0.42	**0.51**
Na	0.84	15	0.27	1.30	97.5	**0.85**	−0.15	0.09	0.20	0.19	0.11
Ni	0.78	16	0.21	1.00	98.5	0.29	−0.02	0.08	−0.02	**0.82**	−0.11
NO_3	0.97	17	0.18	0.90	99.3	0.31	−0.07	0.09	**0.93**	−0.03	0.01
pH	0.58	18	0.13	0.60	99.9	−0.38	**0.51**	0.33	−0.07	−0.10	−0.23
Si	0.69	19				0.05	0.00	**−0.82**	−0.09	0.03	−0.05
SO_4	0.84	20				**0.88**	0.01	−0.23	0.04	0.11	−0.06
TDS	0.77	21				**0.85**	0.05	0.09	0.09	0.14	0.03

Significant factor loadings with more than 0.50 are given in bold

increase in the concentration of Cr(VI) gradually decreases the concentration of Ni in groundwater.

The results show that six factors account for 75 % of the variance in the data (Table 6). The trivalent, hexavalent and total Cr concentrations in groundwater during winter are loaded on factor 2, which describes 14.2 % of the variance. The pH has positive loading and Fe has negative loading on this factor. The high positive factor loading of hexavalent Cr (0.8806) when compared to trivalent (0.6863) form indicates that the contribution of Cr(VI) to total Cr is more during winter season and is controlled by the pH in groundwater. The influence of Fe is negative during this season.

Conclusions

The following conclusions have been drawn from principle component and R-mode factor analysis: (1) At least four factors control the groundwater chemistry of the study area. (2) The association between trivalent, hexavalent and total Cr suggests that most of the Cr during summer is trivalent and that during winter is hexavalent. The hexavalent chromium is more mobile than trivalent in biological system and hence affects human health, particularly the kidney, if consumed beyond the permissible levels for a longer time. They are classified under the category of carcinogenic elements by WHO, and their excess use is capable of altering epidemiological cycle of human beings. Reports and interactions with people in the study area have shown prevalence of cancer among elders compared with surrounding regions (Periakali 1995; Satyanarayanan and Periakali 2004). The incompatibility of Cr with major elements suggests that the Cr species are mainly derived from mining wastes. (3) The major ions Mg, Na, Cl and SO_4 in water are derived from the country rock including the mining waste due to dissolution of minerals, thereby altering the quality of groundwater.

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